AD 718557

8 March 1968 3922 Materiel Test Procedure 5-2-534
White Sands Missile Range

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

MISSILEBORNE COMPUTERS (ELECTRO-MECHANICAL)

1. OBJECTIVE

The objective of this test procedure is to present standard accepted means for evaluating the performance of electro-mechanical computers and determining their conformance to applicable specifications.

2. BACKGROUND

Electro-mechanical computers are used in missile systems to translate data pertaining to time, physical position, acceleration, velocity, attitude, mechanical motion resolution of coordinate information, pressure, and are also used to generate pitch and yaw programming signals. Since the ultimate success of a missile flight depends upon the proper operation of each component within the missile system, tests and evaluations are performed to determine limitations and other characteristics of electro-mechanical computers to determine their suitability for use in a missile system.

3. REQUIRED EQUIPMENT

a. Oscillograph recorder (two channel)
b. Frequency sensitive voltmeter
c. Vacuum tube voltmeter
d. Phase sensitive voltmeter
e. Null meter
f. Dual-trace oscilloscope or servoscope
g. Filter
h. Calibrated divider
i. Dividing head
j. Excitation source (power supply)
k. Bridge
l. Indexing head
m. Precision ratio XFMR
n. Summing XFMR
o. Phase inverter
p. Quadrature generator
q. Phase shifter
r. Precision angle positioner

4. REFERENCES

A. The International Dictionary of Physics and Electronics, Second Edition, D. Van Nostrand Co., Inc., Princeton, New Jersey, 1961.
B. Chamber's Technical Dictionary, Third Edition Revised, MacMillan Company, New York, New York, 1962.
C. Kearfott Division of General Precision, Inc., Little Falls, New Jersey.

Volume 1, Servo Motors, Motor Generators, Synchros
Volume 3, Gyros, Platforms, Accelerometers
Volume 4, Synchros and Resolvers, Motors and Motor Generators, Gyros, Accelerometers

5. SCOPE

5.1 SUMMARY

This document describes the following method of testing the e-m computers considered to be within the scope of the MTP and the typical applications for each.

a. Resistance Potentiometers - A test to evaluate and determine repeatability, electrical error, linearity degradation, noise, phase shift, temperature, null voltage, and input current.

b. Induction Potentiometers - A test to evaluate and determine electrical error, transformation ratio, null voltage, and input current.

c. Synchros - A test to evaluate and determine the fundamental null voltage, total null voltage, electrical zero positions of synchro transmitters and transformers, transformation ratio, phase shift, electrical error and inter axis error.

d. Resolvers - A test to evaluate and determine the same characteristics listed for synchro type e-m computers plus the determination of resolver functional error.

5.2 LIMITATIONS

The procedures contained in the MTP are limited to an investigation of e-m computers, through a program designed to evaluate the functional operation of typical computers used to measure, control, and process electrical and mechanical functions in missile applications. The procedures, considerations, and tests were made general to provide coverage of various types of similar systems and their functions. Test and evaluation procedures for specific components within a given computer are covered in other MTP's.

6. PROCEDURES

6.1 PREPARATION FOR TEST

All test personnel must be thoroughly familiar with the units they are to test and with the test equipment and facilities, they are to use. A discussion of potentiometers, synchros, and resolvers is contained in the Appendix. All available manuals, specifications, and data must be understood to select the proper test equipment and prepare the test. The test equipment should have an accuracy of at least 10 times that of the unit to be tested. Suitable safety precautions must be provided at all times to protect the operator, other personnel, equipment, and the testing facility.

6.2 TEST CONDUCT

6.2.1 Resistance Potentiometers

The required characteristics for resistance potentiometers can be found by the methods shown in Table I.

Characteristic	Test Method
Repeatability	Static Calibration
Electrical Error	Static Calibration
Linearity Degradation	Static Calibration
Noise	Measurement of the unbalanced current on an oscillograph over a small angular displacement.
Phase Shift	Static Calibration
Temperature	Static Calibration at the desired temperature

Table I. E-M Computer Characteristics and Test Methods

It is apparent from Table I that all required characteristics can be obtained using the same method with slight modifications. The circuit for this method is shown in Figure 1.

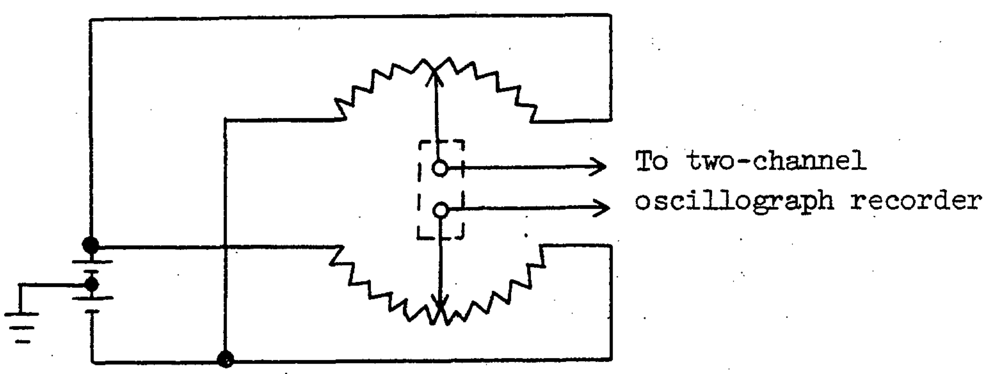


Figure 1. Basic Wiring Method for Static Tests.

The following procedural steps are used to determine the characteristics of resistance potentiometers with modifications for Noise and Temperature tests as noted in Table I.

a. Connect equipment as shown in Figure 1.
b. Position potentiometer shaft incrementally with known values

c. Monitor and record the electrical output with oscillograph or precision voltmeter

6.2.2 Induction Potentiometers

6.2.2.1 Electrical Error

a. Connect equipment as shown in Figure 2a.
b. Incrementally position rotor through a (±) 90 degree range
c. Record output voltage

6.2.2.2 Transformation Ratio

a. Connect equipment as shown in Figure 2b
b. Rotate potentiometer rotor to the position giving peak deflection on frequency sensitive voltmeter (FSVM)
c. Measure the root-mean-square (RMS) value of the induced fundamental secondary voltage ratio to the RMS value of the excitation voltage.

6.2.2.3 Null Voltage

a. Connect equipment as shown in Figure 2c. The filter shown in this diagram must have a sharp cutoff characteristic permitting only voltages of the same frequency as the excitation to be measured.
b. Turn potentiometer rotor to position giving minimum reading on meter. This is the fundamental or output null at the excitation frequency.

6.2.2.4 Input Current

a. Connect equipment as shown in Figure 2d
b. Measure total RMS value of primary current with secondary open and rated voltage applied to primary test diagram.

6.2.3 Synchros

6.2.3.1 Fundamental and Total Null Voltage

Both the fundamental null voltage and total null voltage may be obtained by the following method described.

a. Connect equipment as shown in Figure 3.
b. Turn the rotor under test until a minimum voltage is obtained at the meter. The indication on the F.S.V.M. is the fundamental null voltage.
c. To obtain a total null, the rotor is left in the above established position.
d. Connect a VTVM to the secondary and read the null voltage.
e. Repeat the above procedure and check for null readings at every 60 degree rotation of the rotor.

6.2.3.2 Electrical Zero

In any synchro system that is expected to operate with any degree of

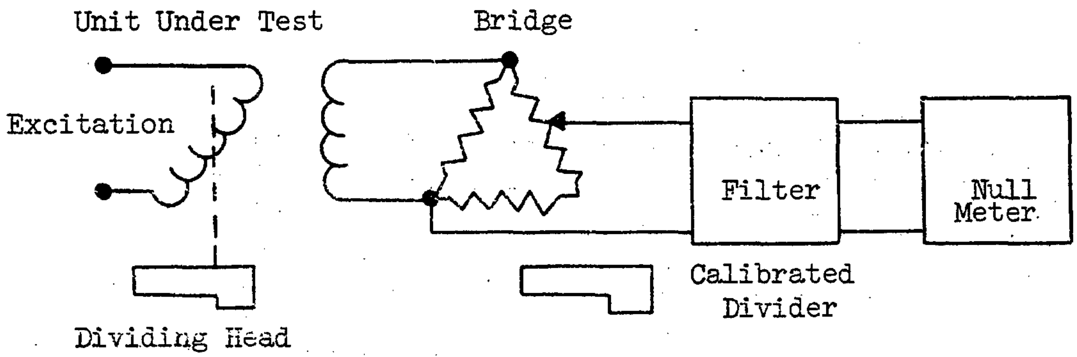


Figure 2A. Electrical Error Test Diagram

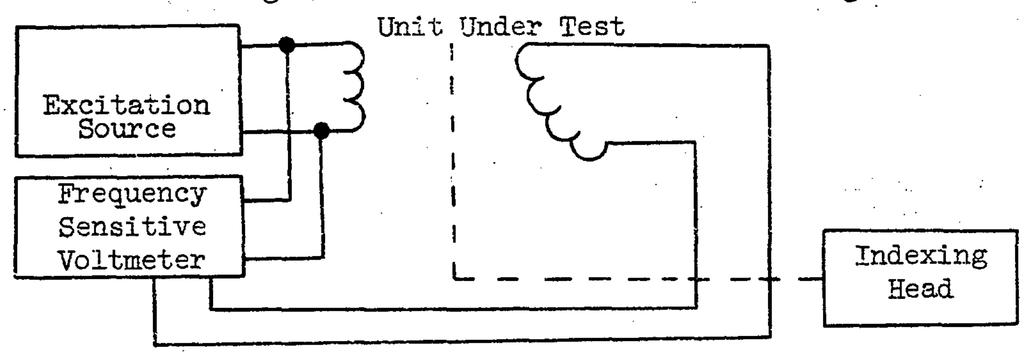


Figure 2B. Transformation Ratio Test Diagram

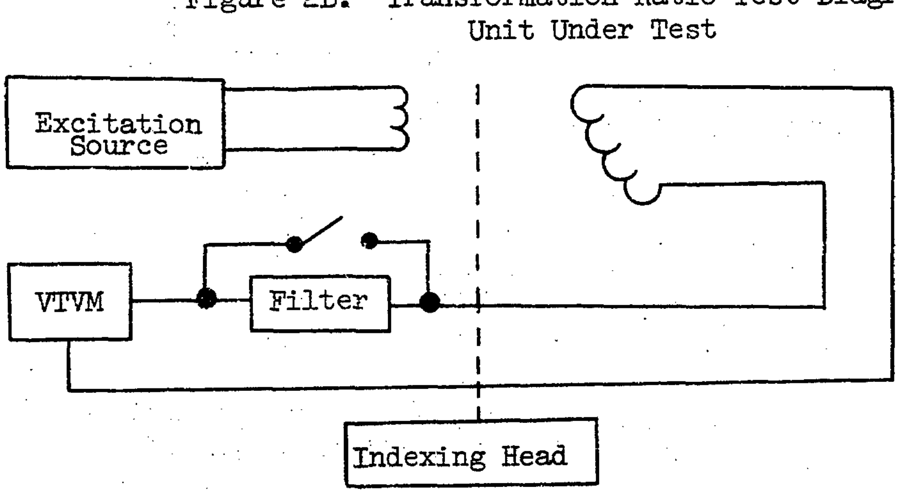


Figure 2C. Null Voltage Test Diagram

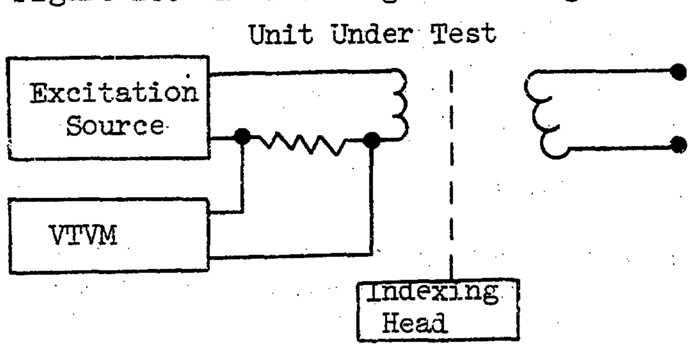


Figure 2D. Input Current Test Diagram

Figure 2. Suggested Wiring Methods

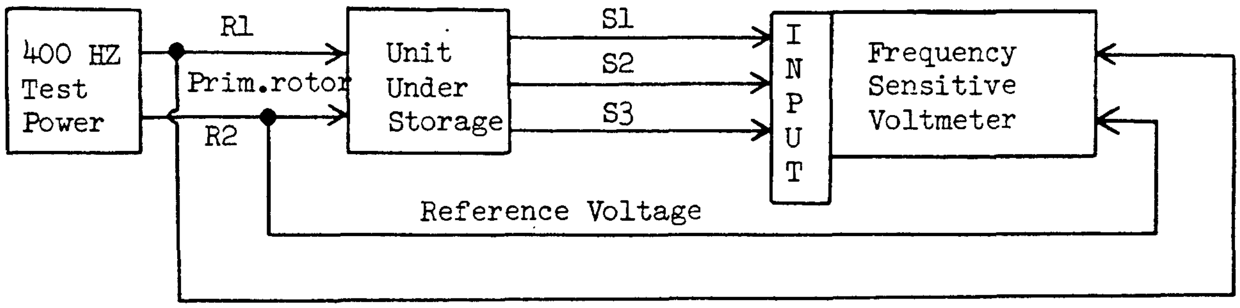


Figure 3. Basic Diagram Used to Obtain a Null Voltage Measurement

accuracy, it is highly important that the units be electrically zeroed. For a synchro to be in a position of electrical zero, the voltage between S1 and S3, must be zero, and the phase of the voltage at S2, must be the same as the phase of the voltage at R1.

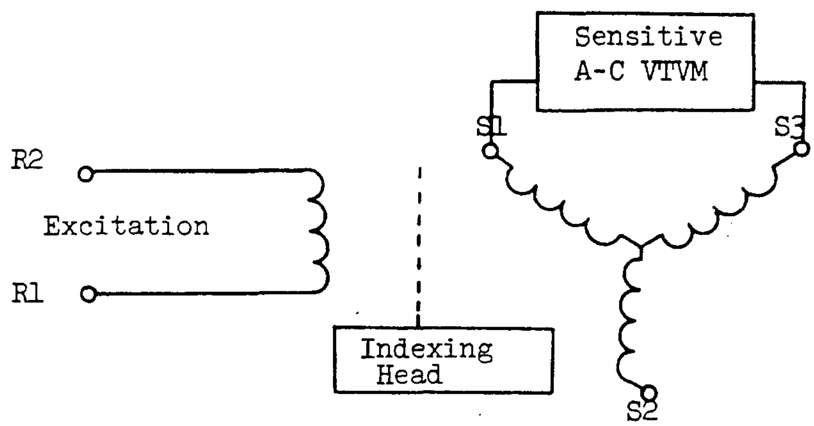


Figure 4. Test Equipment Arrangement for Accurately Determining Electrical Zero Position of a Synchro CX.

a. Connect equipment as shown in Figure 4 or 5.

b. Rotate the synchro rotor shaft to the position producing the minimum reading on the VTVM.

c. To determine the mean value of the measurement, no fewer than five readings should be documented.

6.2.3.3 Transformation Ratio

To determine the transformation ratio, the voltage divider method is the most common and is considered appropriate for laboratory work.

a. Connect equipment as shown in Figure 6.

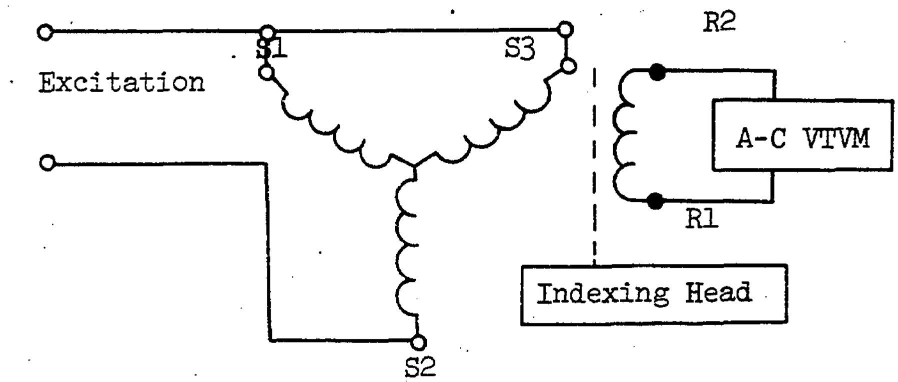


Figure 5. Electrical Arrangement for Accurate Measurement of Electrical Zero on Synchro Transformers (CT).

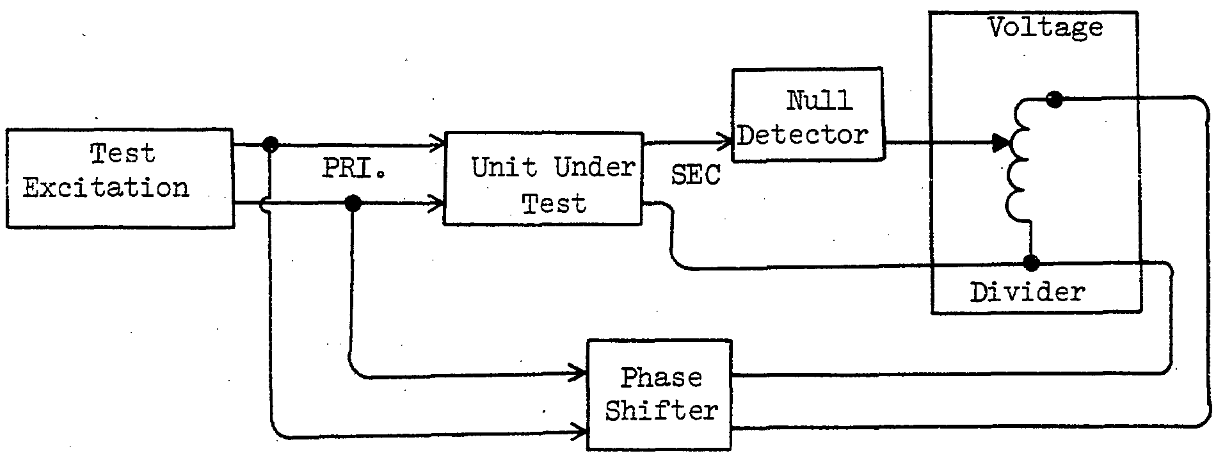


Figure 6. Electrical Arrangement of Equipment used to Determine Transformation Ratio.

b. Shift the phase of the synchro primary voltage by the amount of phase shift existing between primary and secondary windings. Phase shift is determined by the method outlined in section 6.2.2.

c. Apply the phase shifted primary voltage to the input of a precision voltage divider which has a direct readout of its voltage ratio setting.

d. Connect the tapped voltage from the voltage divider (ratio transformer) through a null detector to the secondary winding of the unit under test.

e. Adjust the voltage divider until null is indicated on the null detector.

f. The transformation ratio will be the voltage ratio setting indicated on the voltage divider device. A high precision angle positioner and phase sensitive voltmeter are required to establish position of maximum coupling.

Another method of determining a transformation ratio, is by the

demodulation of the primary and secondary voltages of the unit under test and comparing these signals.

6.2.3.4 Synchro Phase Shift

To determine synchro phase shift, the null method is utilized.

a. Connect equipment as shown in Figure 7.

b. Phase shift the primary voltage of the unit under test by an arbitrary amount (the phase shifter is usually incorporated in the PSVM).

c. Use the phase shifter primary voltage as reference to a PSVM.

d. Apply the secondary voltage to the input of the PSVM.

e. Adjust the phase shifter until null is indicated on the PSVM. This indicates that the PSVM reference voltage is now in phase with the PSVM input.

f. The angle observed on the phase shifter is the actual phase shift between the primary and secondary of the unit under test.

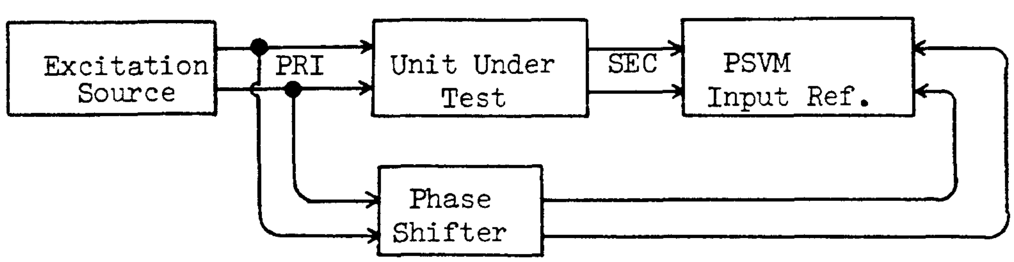


Figure 7. Electrical Arrangement used in Performing Phase Shift Measurements by the Null Method.

An alternate method of checking phase shift, utilizes an oscilloscope rather than the PSVM. Figure 8, shows the equipment line up.

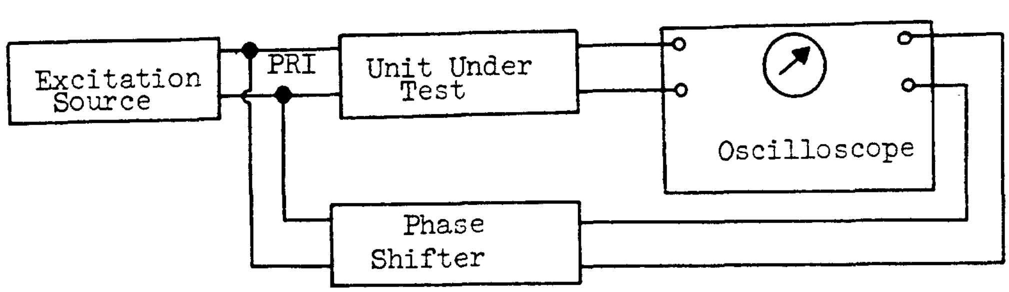


Figure 8. Equipment Arrangement Used in Measuring Phase Shift by the Oscilloscope Method.

a. Adjust the phase shifter for an in phase lissajous pattern (indicated by a straight closed line positioned obliquely from lower left to upper right on the oscillograph screen).

b. Read angle now indicated on the phase shifter dial. (This is the phase shift between primary and secondary windings of the units under test).

6.2.3.5 Electrical Error

Determine electrical error by using either Precision Resistance Bridge or Proportional Voltage Null methods.

6.2.3.5.1 Precision Resistance Bridge Method

a. Connect stator leads precision resistance bridge as shown in Figure 9.

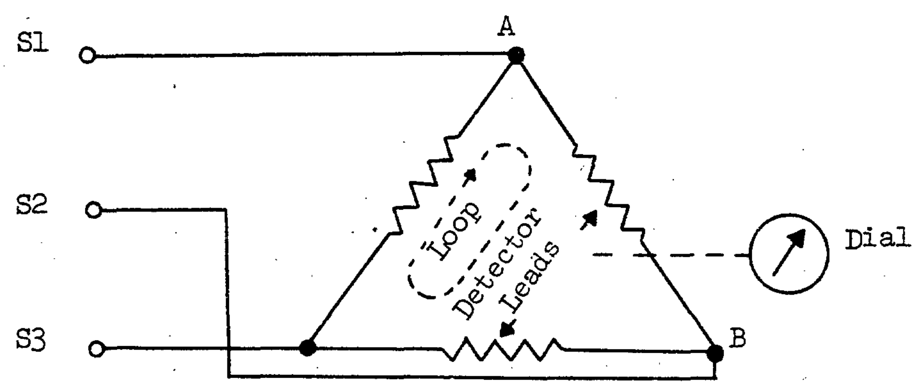


Figure 9. Resistance Bridge Method Used in Analyzing Electrical error characteristics of Synchros.

Two wiper arms (referred to as detector leads) are linked to the bridge dial which indicates movement along the tapped resistors, denoting electrical angle at which detector leads are set. Resistance taps are located according to the formula.

$$R = 1/2 - \frac{3}{2} \quad \text{Cot} \; (\emptyset \pm 60°)$$

R is defined as the ratio of the resistance at the tap to the resistance of the entire leg, and $\emptyset$ is the theoretical shaft angle. The preceding formula is derived from theoretical voltage equations for synchro transmitters given in the appendix. The voltage across the detector leads is considered zero. Kirchoff's voltage law is applied around the loop as shown in Figure 9 and the following equation evolves:

$$nE \sin \emptyset + R \, nE \sin (\emptyset + 240°) = 0$$

R is solved for, and various trigonometric substitutions are used to put R into the form given previously.

6.2.3.5.2 Proportional Voltage Null Method

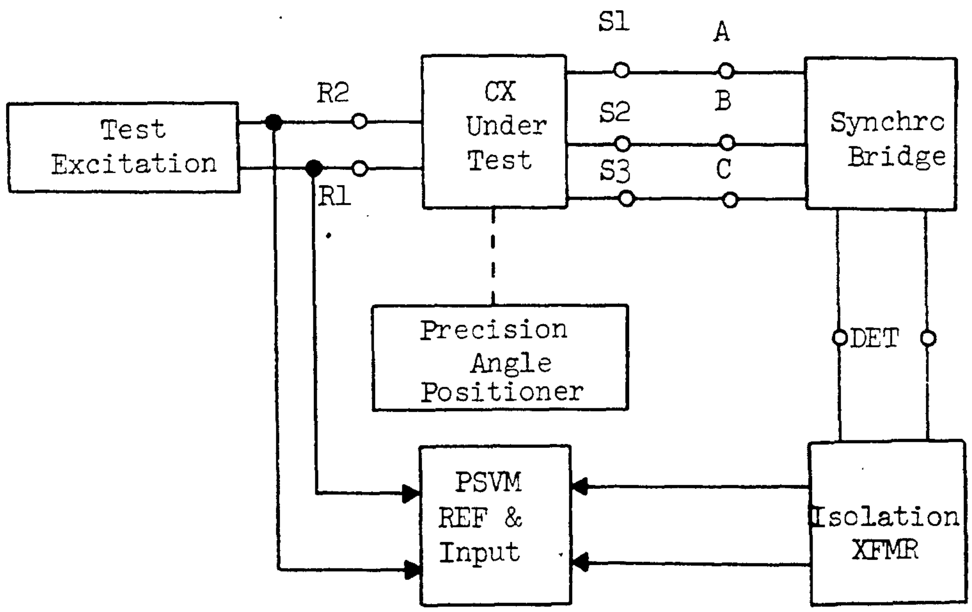


Figure 10. Electrical Arrangement of Equipment Used in Determining Electrical Error by the Proportional Null Method.

a. Connect equipment as shown in Figure 10.

b. Find electrical zero for the CX, then set the precision angle positioner (P.A.P.) so that zero degrees on PAP corresponds to zero degrees on the CX.

c. The synchro bridge and the synchro are then positioned to a 5 degree setting. If the synchro were perfect, the voltmeter would indicate a null. However, since the synchro has an electrical error, the rotor angle is adjusted by means of PAP until a null is indicated on the PSVM.

d. The electrical angle corresponding to the synchro stator voltages (of 5 degrees) is indicated on the dial.

e. Electrical error (mechanical rotor angle minus electrical angle) is indicated on the PAP. This procedure is repeated throughout the entire range from zero through 360 degrees, in 5 degree increments with a null obtained every 5 degrees.

6.2.4 Resolvers

Measurements to be made on resolvers correspond closely, and are accomplished by methods similar, to those used in performing measurements on synchros. Noteworthy differences in measurements are interconnections, particularly for determining electrical zero, and the requirement to determine functional error in resolvers.

6.2.4.1 Electrical Zero

a. Connect equipment as shown in Figure 11 (Resolver Transmitter) or

Figure 12 (Resolver Control Transformer).

b. Rotate the rotor to a position producing a minimum voltage reading on the meter.

c. Repeat no fewer than five times to determine a valid mean.

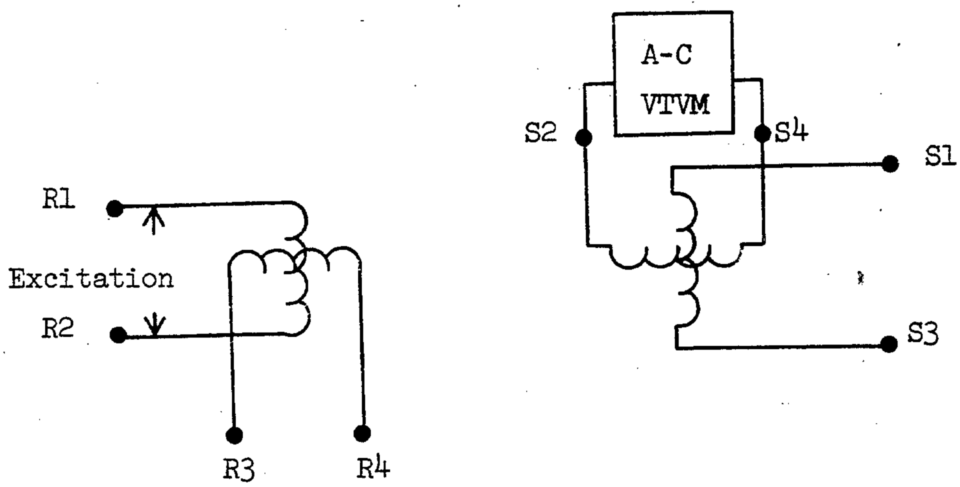


Figure 11. Interconnections of Equipment Used in Determining Electrical Zero in a Resolver Transmitter

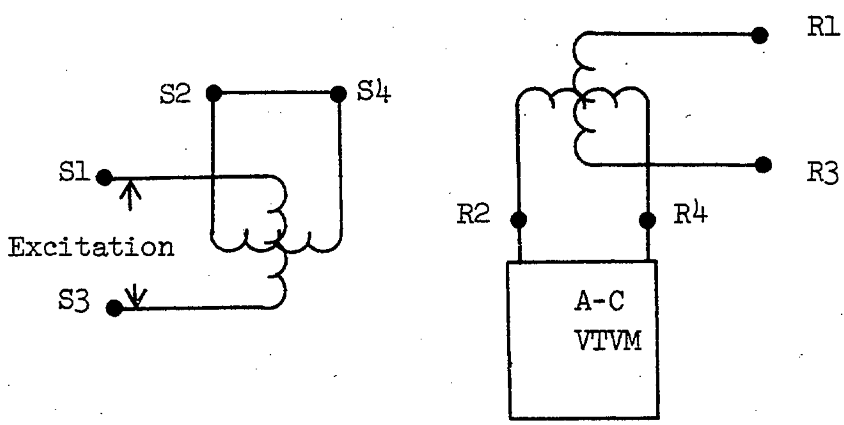


Figure 12. Interconnections of Equipment used in Determining Electrical Zero in a Resolver Control Transformer

6.2.4.2 Functional Error

This is a check of the ability of separate windings to generate a sine or cosine output. Two methods may be used to determine this characteristic. The first method utilizes the same procedure as that transformation ratio with the exception of measuring at many discrete rotor angles from zero through

360 degrees instead of at one rotor angle.

The complex ratio method requires more equipment, is more complex, but offers greater accuracy.

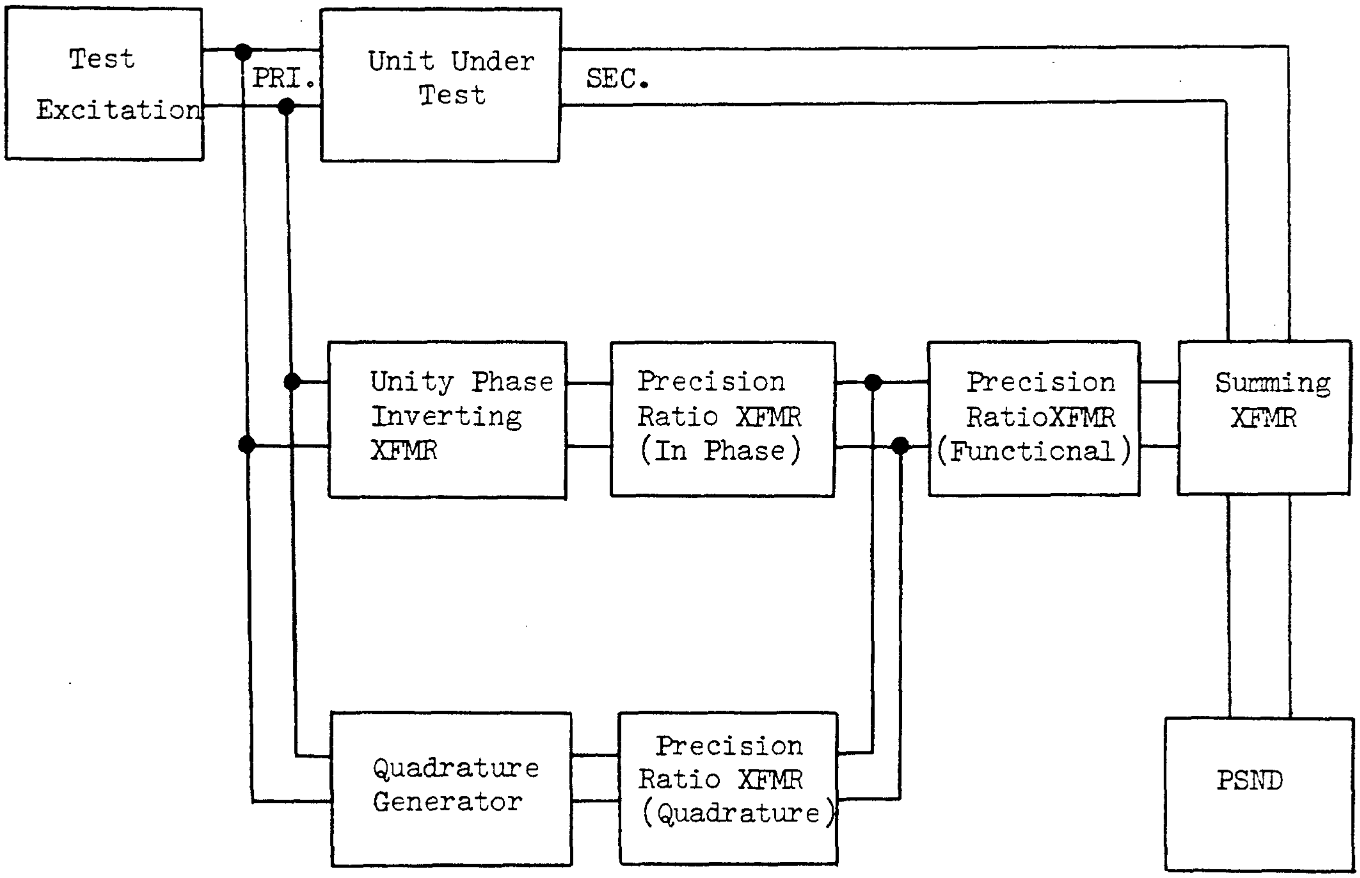


Figure 13. Test Equipment Arrangement Suggested for Performing Functional Error Measurement on Resolvers Using the Complex Ratio Method.

a. Connect equipment as shown in Figure 13.
b. Set the precision (functional) ratio transformer to unity.
c. With the resolver set at minimum coupling the summation of inphase and quadrature ratio transformers generates a voltage equal to the maximum output voltage of the unit both in phase and magnitude.

6.3 TEST DATA

6.3.1 Repeatability

a. Record the results obtained during the conduct of the test.
b. Identify the test records by; unit under test, place, time and environmental conditions.

c. Repeatability can only be checked by running the test a number of times.

6.3.2 Electrical Error

a. Record the results obtained during the conduct of the test.
b. Identify the test records by, unit under test, place, time, and environmental conditions.
c. A precision power supply is required for this test.

6.3.3 Linearity

a. Record the results obtained during the conduct of the test.
b. Identify the test records by; unit under test, place, time and environmental conditions.
c. A proper mechanical to electrical alignment is required for the test.

6.3.4 Noise

a. Can be determined by observing the records of past tests
b. Signal quality of the individual tests can be expected to deteriorate over periods of time.
c. Noise can be easily seen on a scope or brush type recording.

6.3.5 Phase Shift

a. Record the results obtained during conduct of the test.
b. Identify the test records by; unit under test, place, time and environmental conditions.
c. Phase shift can be readily observed on a dual type oscilloscope on servo scope.

6.3.6 Temperature

a. Record the data obtained during conduct of the test.
b. An accurate record of the environmental conditions present during test conduct is a necessity.
c. A varying temperature may be a direct cause of a drifting signal.

6.3.7 Transformation Ratio

a. Record the data obtained during conduct of the test:
b. Identify the records by; unit under test, place, time and environmental conditions.
c. Frequency sensitive voltmeter must be utilized.

6.3.8 Null Voltage

a. Record the data obtained during conduct of the test.
b. Identify the records by; unit under test, place time and

environmental conditions.

c. The frequency filter used for this test must have a sharp cut off characteristic permitting only voltages of the same frequency as the excitation to be measured.

6.3.9 Input Current

a. Record the data obtained during conduct of the test.

b. Identify the records by, unit under test, place, time and environmental conditions.

An important requirement for obtaining test data from the above mentioned tests is the proper calibrations of all test equipments.

The operator should hold two preliminary checks

a. Visual:

1) Check for proper markings, configuration and identification.

2) Check for proper preservation, during handling, packaging or shipping.

b. Assurance:

1) That test equipment and accessories are operational and meet certified calibration requirements.

6.4 DATA REDUCTION AND EVALUATION

Whenever possible, records and presentations of data obtained for standard equipment and production items should adhere to TM 38-750-1, "The Army Equipment Record System (TAERS)". However, this system is not adequate for data acquired for nonstandard or special equipment.

6.4.1 Repeatability

Is taken as a deviation of results found at the same test point on the potentiometer.

6.4.2 Electrical Error

The input and output voltages are measured to a specific tolerance. Total error is based on an error of shaft angular position, and a specific voltage limit of error in input and output voltages.

6.4.3 Linearity

Is determined by voltage measurements for ascending and descending values of shaft rotation or position while recording the linear relation between electrical output and angular shaft position.

6.4.4 Noise

The noise level can be expected to increase throughout the life of the potentiometer. Tests will show existing discontinuities and spurious, low level, signals on the recorded data.

6.4.5 Phase Shift

An applied input signal is compared with the output waveform on a dual trace oscilloscope or servo scope. Where potentiometers are used in an a-c system, stray capacitance and inductance in the resistance element may shift the output voltage out of phase with a reference voltage causing inaccuracies and poor response in servo performance.

6.4.6 Temperature

Check the operation of the various potentiometers under a constant or varying temperature environment.

6.4.7 Discussion

More comprehensive test reports and records may be prepared in accordance with the applicable MTP's covering test reports which list various types of reports and indicate suggested formats and a description of contents.

In the final analysis, data reduction and presentation will depend on the types and amount of data collected. The use of computer is desirable, providing the data are voluminous and compatible with the machine method of data reduction. It is recommended that available data reduction techniques be examined during test planning and the methods of data collection coordinated with the personnel who will eventually attempt to reduce data. Data from any test support groups which may assist in performing the tests will be reduced to the degree specified by the test director.

The results of the investigations and tests presented in this MTP will be in the form of notes, charts, graphs, tables, or other such forms as may apply. Enter all test information, results, and data in the test log or folder including the number of starts on each test, dates, and running times, and all test equipment settings at which the tests were conducted. The tests results should not be based upon a single test, but should be an average of a series of tests to reduce the possibility of erroneous conclusions. All test data and information will become a permanent record in the log. It is important that the log for each system is complete, accurate, and up-to-date, as these logs may be used for future studies. The information derived from these procedures may be reviewed by the appropriate authorities to determine the practicability of using the computer tested for a particular usage.

Equipment evaluation usually will be limited to comparing the test results to the applicable specifications and/or the requirements imposed by the intended usage.

6.4.8 Curves (General)

If the results obtained during a test, do not concur with the original

laboratory curve, the following accepted method is also accepted if no plot at all is available for the test

1) Make a theoretical plot of input values (pressure voltage, displacement etc.) versus desired output results.

2) Make a minimum of 3 curves utilizing as many points as deemed necessary to establish a reliable plot.

3) Make an average curve from the results obtained from the previous runs. This curve can now be used as a reliable calibration curve.

4) Make one more test run and compare it to the new calibration curve. The deviation should be held to an accuracy of less than 5%.

GLOSSARY

Terms Associated with Potentiometer E-M Computers:

1. Electrical Error: A measure of accuracy or reliability of the electromechanical device, measured as the difference between the angular (mechanical) position and the electrical position.
2. Repeatability: The stability or the persistence of a potentiometer to ingeminate, and is a function of the mechanical or electrical backlash.
3. Linear Degradation: A lessened accuracy in the output of a potentiometer as a result of wear. Wear is accelerated by excessive rotation, operation at high temperatures, or excessive loads.
4. Phase Shift in A-C Performance: Where potentiometers are used in a-c systems, stray capacitance and inductance in the resistance element may shift the output voltage out of phase (phase shift) with a reference voltage, causing inaccuracies and poor response in servo performance.
5. Transformation Ratio: The ratio of the maximum, no-load, rms value of the induced fundamental secondary voltage to the rms value of the excitation voltage.
6. Null Voltage: A null occurs when the no-load rms value of the fundamental secondary voltage component, which is in time phase with the secondary voltage at maximum coupling, is minimum.

Terms associated with synchro and resolver E-M Computers:

7. Output Voltage: The open circuit fundamental line-to-line output voltage at maximum coupling under rated excitation. Output voltage is also given as a voltage gradient in volts per unit of angular displacement. For all types except induction potentiometers, this is expressed as: Voltage gradient = volts at maximum coupling x sine $1^\circ(V/^\circ)$.
8. Electrical Zero: Electrical zero is the relative position of the rotor and stator that results in a minimum, or null, output voltage.
9. Rotor Angle: The angular mechanical displacement of the rotor shaft from electrical zero. Standard positions of the rotor counterclockwise viewed from the shaft end of the synchro (or resolver).
10. Electrical Angle: The theoretical position the rotor is supposed to have attained, according to measured electrical voltage.
11. Time Phase: The phase relation between voltages of any point in a synchro (or resolver), and the excitation voltage. Time phase is expressed in degrees.
12. Transformation Ratio: The ratio of the fundamental component of the no-load secondary voltage to the voltage applied to the primary at first maximum coupling. This is usually denoted by the letter "n" in equations for various types of synchros and resolvers.
13. Phase Shift: The difference between the time phase of the fundamental component of the primary and secondary voltages at the maximum coupling position of the rotor. It is measured at the first position of maximum coupling counterclockwise from electrical zero. Phase shift of synchros and resolvers is usually leading in nature and is expressed in degrees.
14. Null Voltages: For synchros, null voltage positions of the rotor are found every 60 degrees of rotor angle, where there is minimum voltage induced

into secondary winding. For resolvers, null voltage positions of the rotor are found every 45 degrees and/or every 90 degrees.

15. Fundamental Null: The fundamental component at the excitation frequency of a secondary voltage measured at a null position.
16. Total Null Voltage: The minimum secondary rms voltage (including harmonics) measured at a null position.
17. Electrical Error: The difference between the mechanical position and the electrical position. Mechanical position is the actual or measured angle that the rotor has attained. Electrical position is the theoretical angle that the rotor is supposed to have attained, according to measured electrical voltages.
18. Functional Error: The difference between output voltages actually measured and output voltages derived from equations for various rotor angles. Functional error tests are performed on resolvers only.
19. Interaxis Error: The deviation of mechanical position from electrical position while measurement is made at null positions for all rotor, stator, and rotor-stator combinations.
20. Static Calibration: A measurement made of stationary electrical charges, relevant to potentiometer testing. For example, the change in voltage may be measured at one position of the potentiometer rotor, the rotating the rotor to another position and making another measurement.

APPENDIX A

DISCUSSION & TESTING OF E-M COMPUTERS

Resistance Potentiometers

A typical potentiometer type e-m computer, which may provide a precise and stable voltage proportional to the signal input and shaft movement, is one which may incorporate a feedback potentiometer and a measuring potentiometer, these being physically united but in electrically separate circuits. This is an integrated potentiometer assembly and the wiper arms of both potentiometers are driven simultaneously by the same source. In a typical application in guided missiles the potentiometer may be positioned by servo action, air pressure, hydraulic pressure temperature and displacement. The individual power supplies gives this design a high degree of reliability.

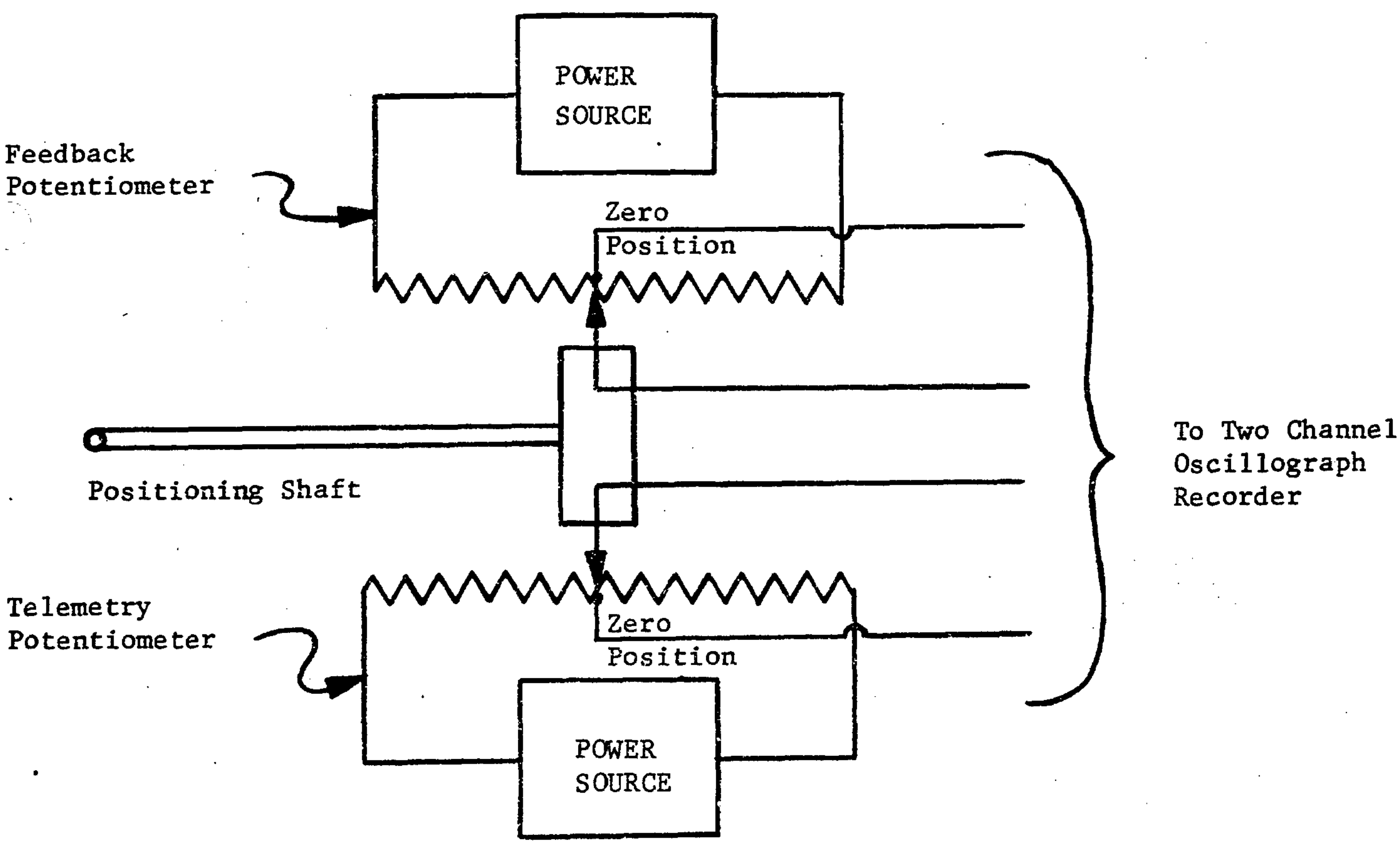


Figure A-1. A basic Application of this Principal.

Rotary potentiometers usually have a configuration as shown in Figure A-2. Their characteristics can be obtained by the following procedure:

a. Incrementally position, thru synchro action or mechanical displacement, the rotary potentiometer.

b. Record the electrical output on a 2 channel oscillograph.

c. A comparison of the coarse and fine output can determine linearity and offset.

Testing for a rotary potentiometer can be accomplished by tapping, from a 360 degree potentiometer, progressively, varying levels. The voltage derived from potentiometer wiper rotating at a given precalculated rate represents time, and can be used to command maneuvering signal for a missile. Coarse and fine position signals can be determined from this type of potentiometer. For every 360° or 1 revolution on the coarse potentiometer, the fine can be rotated thru gear action for any given amount of revolution. See Figure A-2.

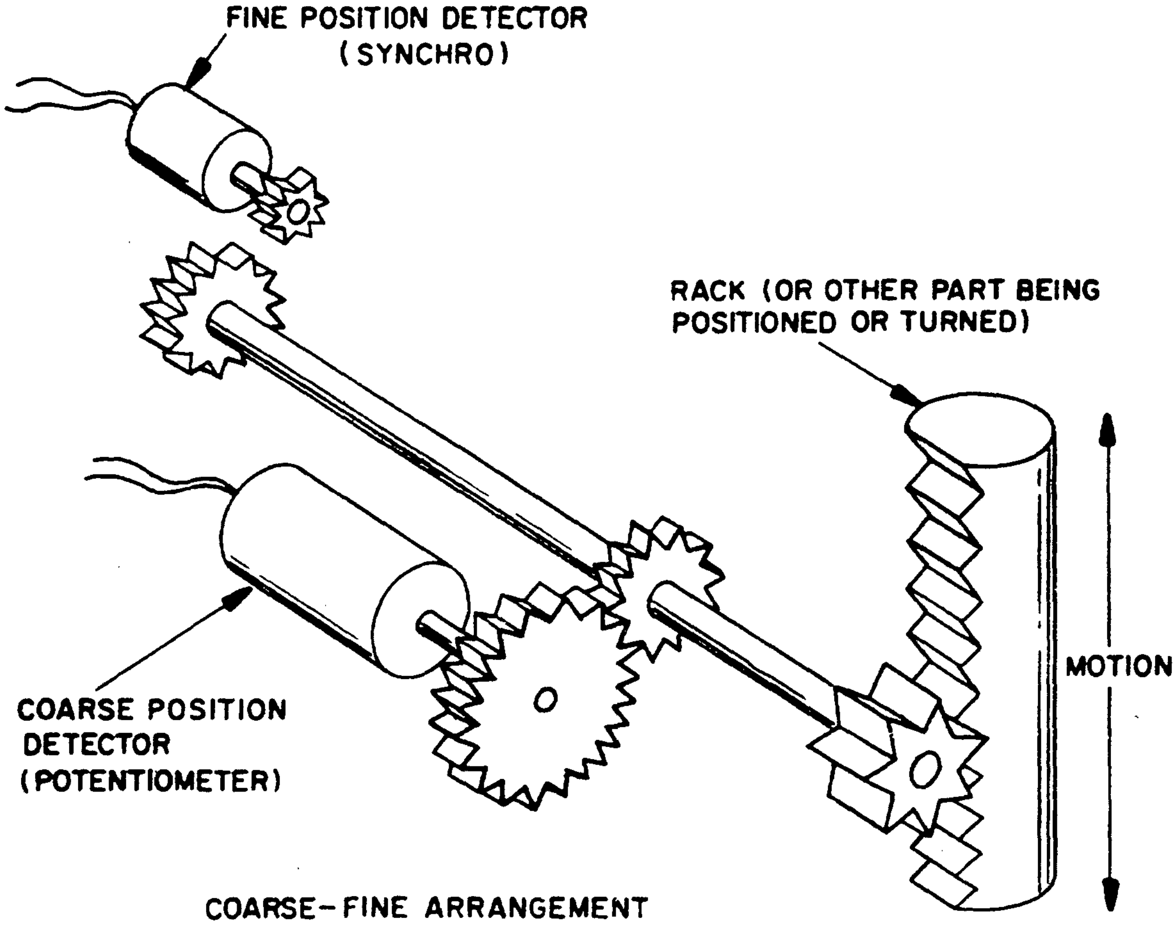


Figure A-2. Coarse and Fine Reading Potentiometer

Every 90° displacement of the coarse potentiometer is equal to 360° of the fine potentiometer. A full revolution of the course potentiometer is. equal to 4 revolutions of the fine potentiometer.

Table I, lists the characteristics of the potentiometer type E-M computers, that can be determined thru tests. In each case, the test or

measuring method used should be selected on the basis which satisfy the sensitivity, range and applicable specifications of the instrument under test.

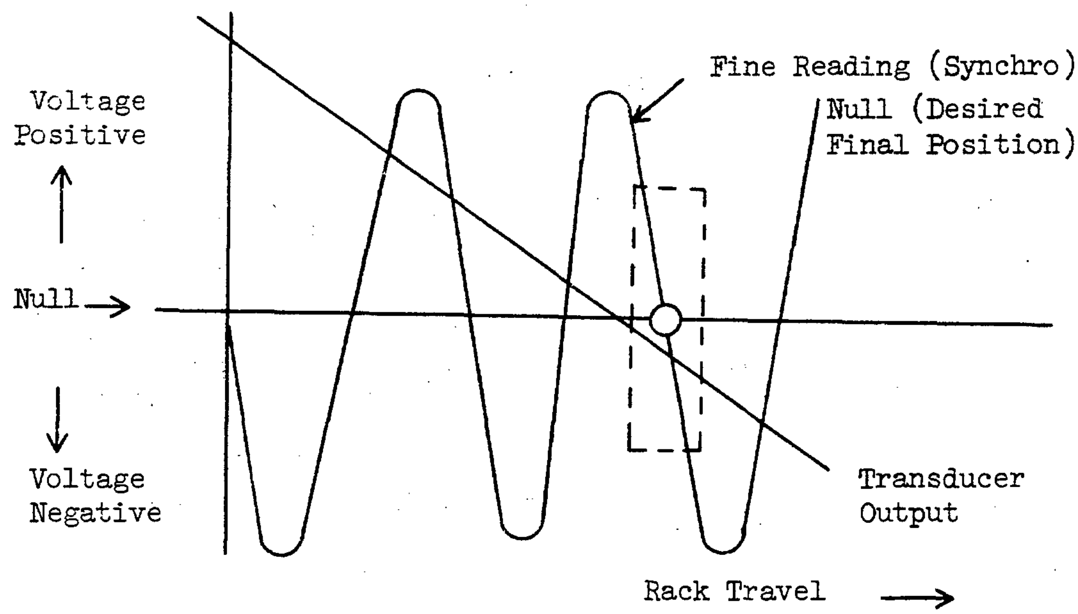


Figure A-3. Coarse Output - Fine Output

Induction Potentiometers -

An induction potentiometer can be considered as another type of rotary transformer, which provides accurate linear indication of shaft rotation about a reference position. The output is proportional to angular displacement and whose phase relationship indicates direction of shaft rotation. Induction potentiometers find use in applications where resistive potentiometers are impractical because of the following features. See Figure A-4.

a. Induction potentiometers have no wiping contacts, and can be used as gyroscope pick-offs.
b. Input and output are isolated
c. Resolution is infinite
d. Noise level is low
e. The total angle of travel is limited to less than 180°

Synchros -

A synchro type E-M computer, Figure A5, is a device used to relate a mechanical angle to electrical voltages. Basically a variable transformer, a synchro consists of rotor and stator windings which can change position with respect to one another. This change in position (mechanical angle) causes a change in the voltage outputs of the synchro. Synchros are designed to perform different functions, and as such, have various relationships between mechanical angles and electrical voltages.

Synchros have either two or three rotor lead wires, and three stator lead wires. The lead wires are identified both by symbol designation and color. Rotor leads are designated R1, R2, and R3; stator leads are S1, S2, and S3.

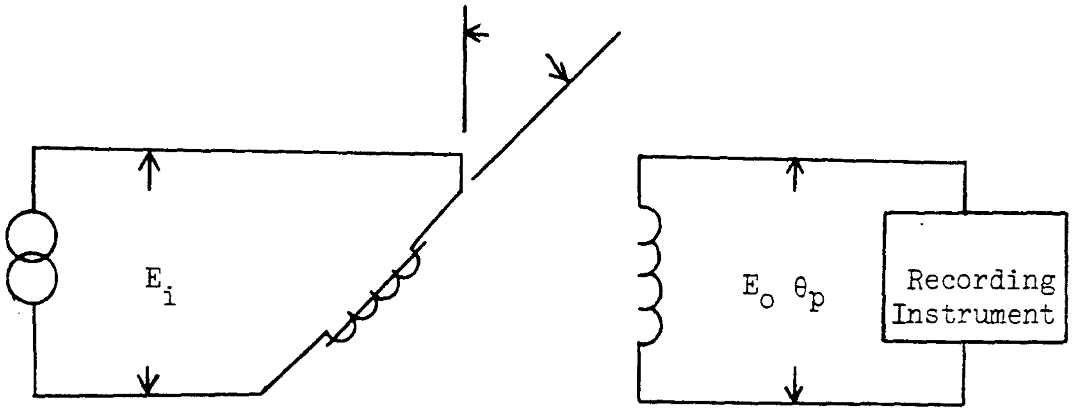


Figure A-4. Basic Application of an Induction Potentiometer

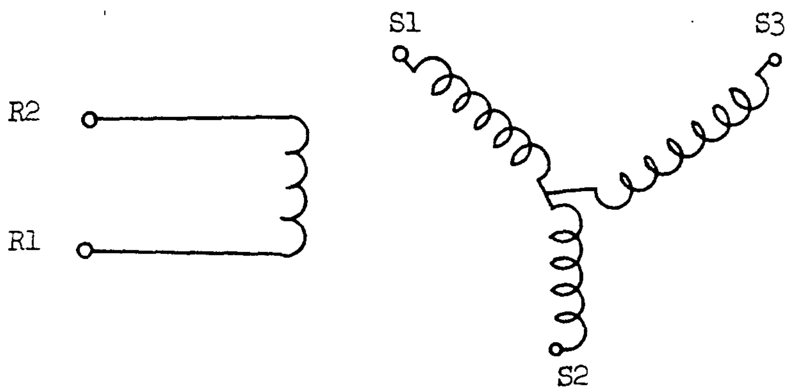


Figure A-5. Symbolic Representation of a Synchro

Synchro Control Transmitter (CX) - Functions of the rotor and stator windings of the control transmitter are:

a. Primary (or input) winding; Rotor
b. Secondary (or output) winding; Stator

Synchro Transformer (CT) - Functions of the rotor and stator windings of the

control transformer are:

a. Primary winding; Stator
b. Secondary winding; Rotor

Synchro Control Transmitter - Electro-mechanical relationships of the synchro control transmitter (CX) are described as follows:

$$E(S_{13}) = nE(R_{21}) \sin \emptyset$$
$$E(S_{32}) = nE(R_{21}) \sin (\emptyset + 120)$$
$$E(S_{21}) = nE(R_{21}) \sin (\emptyset + 240)$$

$E(S_{13})$ is the voltage between stator terminals S1 and S3. The second subscript (S3 in this case) usually is considered the high terminal, and the first subscript (S1), the low terminal. However, the equations remain valid if the first subscript (S1) is considered high and the second subscript (S3) is considered low. Either convention is acceptable as long as consistency is maintained throughout. $E(R_{21})$ is the voltage between rotor terminals R2 and R1. Other voltages are similarly defined; n is the transformation ratio, and $\emptyset$ is the electrical angle.

Functions of the rotor and stator windings of the control transmitter (CX) are:

a. Primary (or input) winding; Rotor
b. Secondary (or output) winding; Stator

Electro-mechanical relationships of a synchro control transformer (CT) may be defined as follows:

$$E(R_{12}) = nE(S_{13}) \sin (\emptyset + 120) + E(S_{32}) \sin \emptyset \; E(S_{13})$$
$$+ E(S_{32}) + E(S_{21}) = 0$$

Control Transformer - Functions of rotor and stator windings of the control transformer (CT) are:

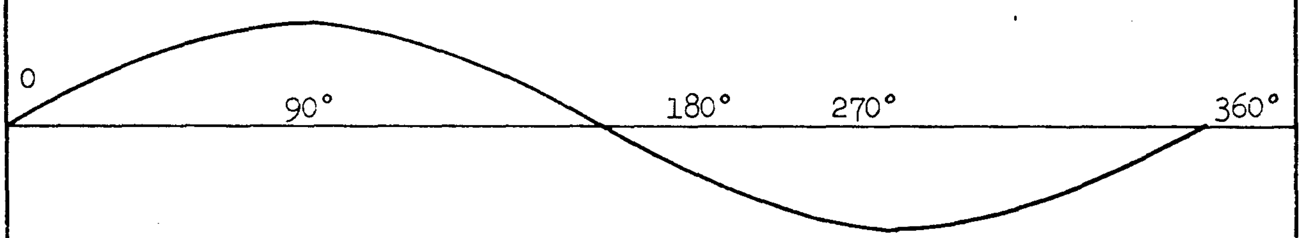
a. Primary winding; Stator
b. Secondary winding; Rotor

A synchro control transformer receives electrical information from a synchro DX and converts this information into another form of electrical information dependent upon the mechanical angle of the synchro CT. If the mechanical angle of the CX and the mechanical angle of the CT are identical, then the resulting electrical output of the CT ideally is zero volts.

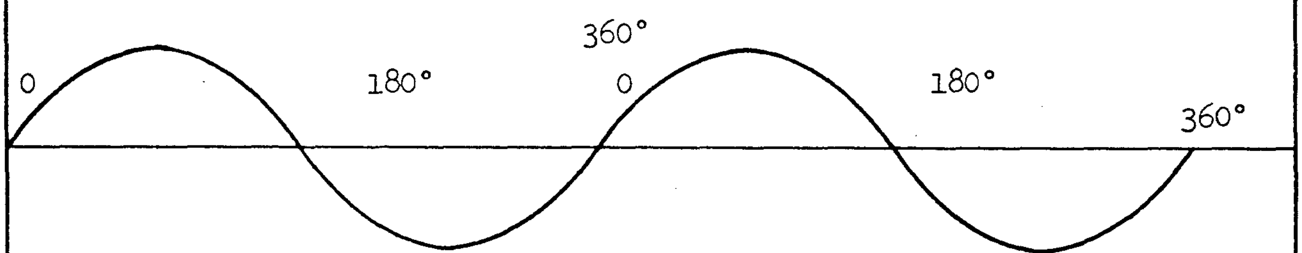
Synchros are commonly used in systems where the synchro output is used to actuate a servo system where the value of the total null voltage is of great importance due to the succeeding circuit servo amplifiers having relatively high gain to process the synchro transmitter output. Total null normally tolerated is no greater than 50 to 60 percent greater than the

permissible fundamental null.

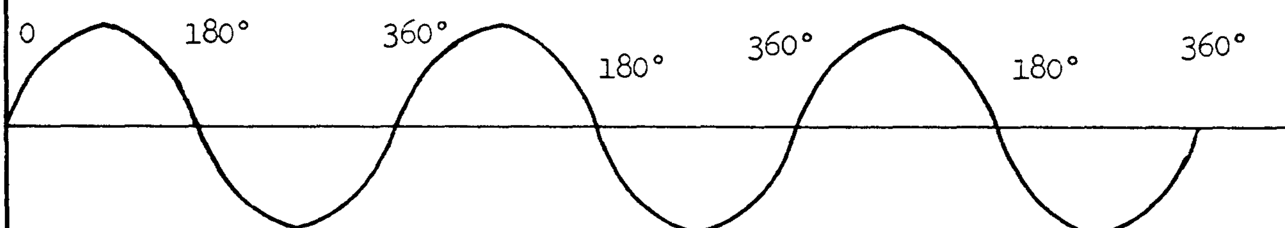
The accuracy of a synchro is determined by manufacturing and design limits, and each source contributes a typical type of error curve. These include one cycle, two cycle and higher frequencies. Various components of error and their cause are shown in evaluation Figure A-6.



One cycle error cause - Rotor eccentricity



Two cycle error cause - Unbalance of interwinding capacitance stator out of round



Higher frequency error cause - (harmonics generated by windings slot combinations.

Figure A-6

An ideal synchro must have an electrically symmetrical rotor rotating exactly in the center of an electrically round hole. Eccentricity, or the amount by which a rotor rotates of the center of the stator have, causes one cycle or

fundamental error.

When the hole or stator deviates from electrical round, a two cycle error results. This error is commonly called the second harmonic, but should not be confused with the frequency content of output voltages. Variation in mechanical roundness, burrs, or other lack of electrical symmetry are primary causes of such error.

The high frequency component shown in the third curve is one contributed by design. Since it is necessary to use stators and rotors made up laminations having discrete slots, high frequency error results.

Resolvers

Resolvers are precision induction type devices used extensively for coordinate transformation, resolution into components, and conversion from rectangular to polar coordinates. A resolver is essentially a variable transformer so designed that its coupling coefficient varies as the sine or cosine of its rotor position. Usually there are two windings on the rotor and stator at right angles to one another.

A resolver is based on the same principles as a synchro. Frequently, resolvers are referred to as "synchro resolvers" and are considered to be a subclassification of synchros. However, it is simpler to refer to synchros and resolvers as two classes of devices based upon the same general principles.

A resolver differs from a synchro in that the former usually has a four-terminal stator, and a two-, three-, or four-terminal rotor, whereas the synchro has the electrical configuration described in the preceding paragraphs.

Resolvers are categorized in two basic types, based upon application; Resolver transmitters (RX), and resolver control transformers (RC).

A resolver transmitter changes information about a mechanical angle from mechanical form into an electrical form useful for computation. Functions of rotor and stator windings are:

a. Primary (excitation) winding; Rotor.
b. Secondary (output) winding; Stator.

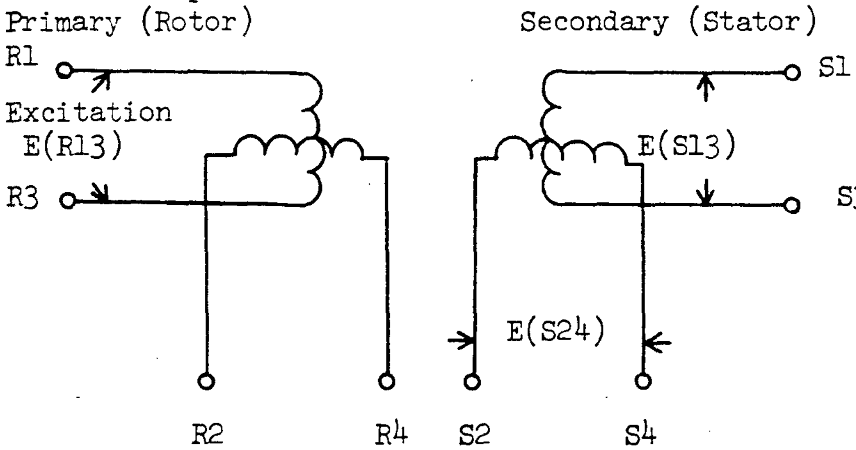
The electrical configuration and corresponding electro-mechanical relationships of a resolver transformer are shown in Figure A-7.

A resolver control transformer is employed to receive electrical information from an RX and convert these data into another form of electrical information, dependent upon the angle of the RC rotor. (If the mechanical angle of the RX and the mechanical angle of the RC are identical, the resulting electrical output of the RC ideally is zero volts.) Functions of rotor and stator windings are:

a. Primary winding: Stator.

b. Secondary winding: Rotor.

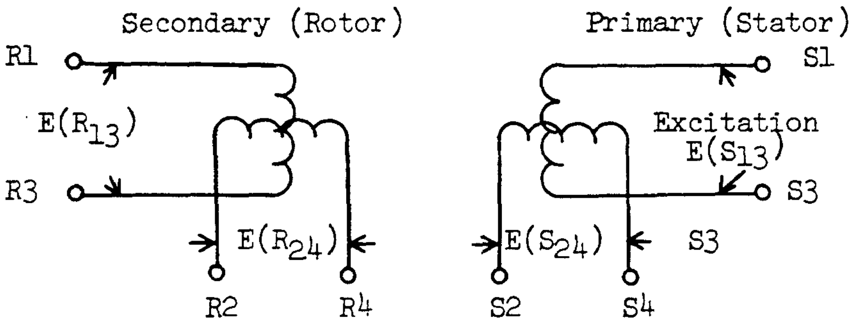
Electrical configuration and corresponding electro-mechanical relationships of a resolver transmitter are shown in Figure A-8.



$E(S13)=nE(R13)\ \cos\phi$
$E(S24)=nE(R13)\ \sin\phi$

Where n is the Transformation Ratio, and ϕ is the phase angle

Figure A-7. Symbolic Representation of a Resolver Transmitter



$$E(R_{24}) = n[E(S_{24})\cos\phi$$

$$E(S_{13})\sin\phi]$$

n and ϕ represent Transformation Ratio and Electrical Angle, respectively.

Figure A-8. Symbolic Representation of a Resolver Control Transformer.

Due to the varied uses of a resolver, a different analysis method would be utilized with each circuit, but certain generalities can be made.

1) The internal impedance of the source exciting a resolver should be as low as possible.
2) The impedance shunting the resolver output should be as high as possible.
3) Spare input windings should be short circuited
4) Both output phases should be loaded with equal impedance.